SECTION III. FUEL-HANDLING AND COMBUSTION EQUIPMENT

2-18. COAL COMBUSTION EQUIPMENT.

Coal may be fired by one of four methods:

— Manually on stationary grates
— Automatically by stoker
— In suspension as pulverized coal
— In a fluidized bed

Manual firing of coal using stationary grates is not used in modern central heating plants because of the limited capacity of hand-fired grates and the amount of labor necessary to operate the equipment. This TM contains no further discussion of manual firing. The following paragraphs describe the combustion equipment required for the other methods of coal firing and typical coal specifications applicable to each each method.

a. Stokers. Stokers were developed to automate and increase the capacity of the simple hand-fired grate. Automatic fuel feed and ash disposal systems were added to reduce the labor requirements, and capacity was increased by the addition of forced draft fans, control dampers, and air compartments to promote better fuel and air mizing. The result is that stokers have several advantages over hand firing: they pemit the use of cheaper grades of fuel, maintain better furnace conditions, increase combustion efficiency, require less labor, and increase the boiler capacity. Stokers may be divided into four general classes: underfeed, spreader, traveling or chain grate, and vibrating grate. Spreader, traveling, chain, and vibrating stokers are overfeed stokers, in that fuel is fed from above the bed. Each type has its own application, depending primarily on the characteristics of the fuel used. The choice of the proper stoker also depends upon factors such as the size and capacity of the boiler, the ash content and clinkering characteristics of the fuel, and the amount of draft available.

b. Underfeed Stokers. Underfeed stokers receive their name from the fact that fresh fuel is supplied below the burning zone. The fuel bed consists of three zones: fresh or green coal on the bottom, the coking zone in the middle, and the incandescent or burning zone on the top. Fresh fuel enters the bottom of one end of a retort, is distributed over the entire retort, and is forced to move gradually to the top where it burns. As the coal travels up from the bottom of the retort, its temperature gradually rises, causing the volatile matter to distill off, mix with the air supply, and pass up through the hotter zones of the fuel bed. The temperature of the mixture of volatile matter and air gradually increases until the mixture ignites and burns. The mixture may burn just below the surface of the fuel bed or immediately above it. The coke remaining after the volatiles have distilled off continues to move to the top; its temperature gradually rises above its ignition temperature and burns. The vertical movement of the coal through the bed is accompanied by movement of the burning coke toward the ash discharge area. The combustion process is practically completed by the time the remaining material reaches this area. The remaining combustible matter or fuel completes its combustion in this area before the ash is removed. Air enters through openings in the stoker called tuyeres, which are usually located at the top or sides of the retort. Underfeed stokers may be classified by the number of retorts (single, double, or multiple) and the method of feeding (screw or ram). Single-retort stokers may be screw- or ram-feed. Figure 2-30 illustrates a single retort, screw- feed ram distributor stoker. Multiple-retort stokers usually combine a gravity or overfeed action with the underfeed, and are always ram feed. They are used only on large boilers. Coal sizing requirements are established by the stoker manufacturer, with a top size of 1½ to 2 inches and not more than 50% slack being typical. The principal elements of an underfeed stoker are hoppers, feeders, retorts, and combustion air fan. Each is discussed in the following paragraphs.

(1) **Hoppers.** Hoppers with a capacity of several hundred to several thousand pouonds of coal are provided to supply fuel to the feeder. Some hoppers are equipped with agitators but most depend on the slope of the hopper sides to prevent coal from bridging. Offset hoppers are occasionally used to permit access to the boiler front.

(2) **Feeders.** Feed screws or reciprocating rams may be used to deliver coal from the hopper to the stoker retort as shown in figure 2-30. Even distribution of the coal is obtained by the shape of the screw, shape of the retort, and the stroke of the distributing rams. The coal feed rate is controlled by a drive mechanism which adjusts the speed of the screw or ram. An electric motor or steam turbine is used to drive the stoker via a mechanical or hydraulic speed reducer. Ram feed stokers may utilize oil-, air-, or steam-driven cylinders to move the ram, and are generally set up to allow multiple feed rates. Shear pins or relief valves are provided to protect the equipment against overload or binding. Belt guards and gear and shaft covers are provided for operator protection.

(3) **Retorts.** The size and shape of the retort depend on the coal-burning capacity of the stoker. Retorts in the smaller units are nearly square, while those in larger units are oblong. The tuyeres or tuyere blocks through which air is admitted to the fuel bed are made in comparatively small sections to allow for expansion and to minimize thermal stress. The tuyere blocks form the top of the retort

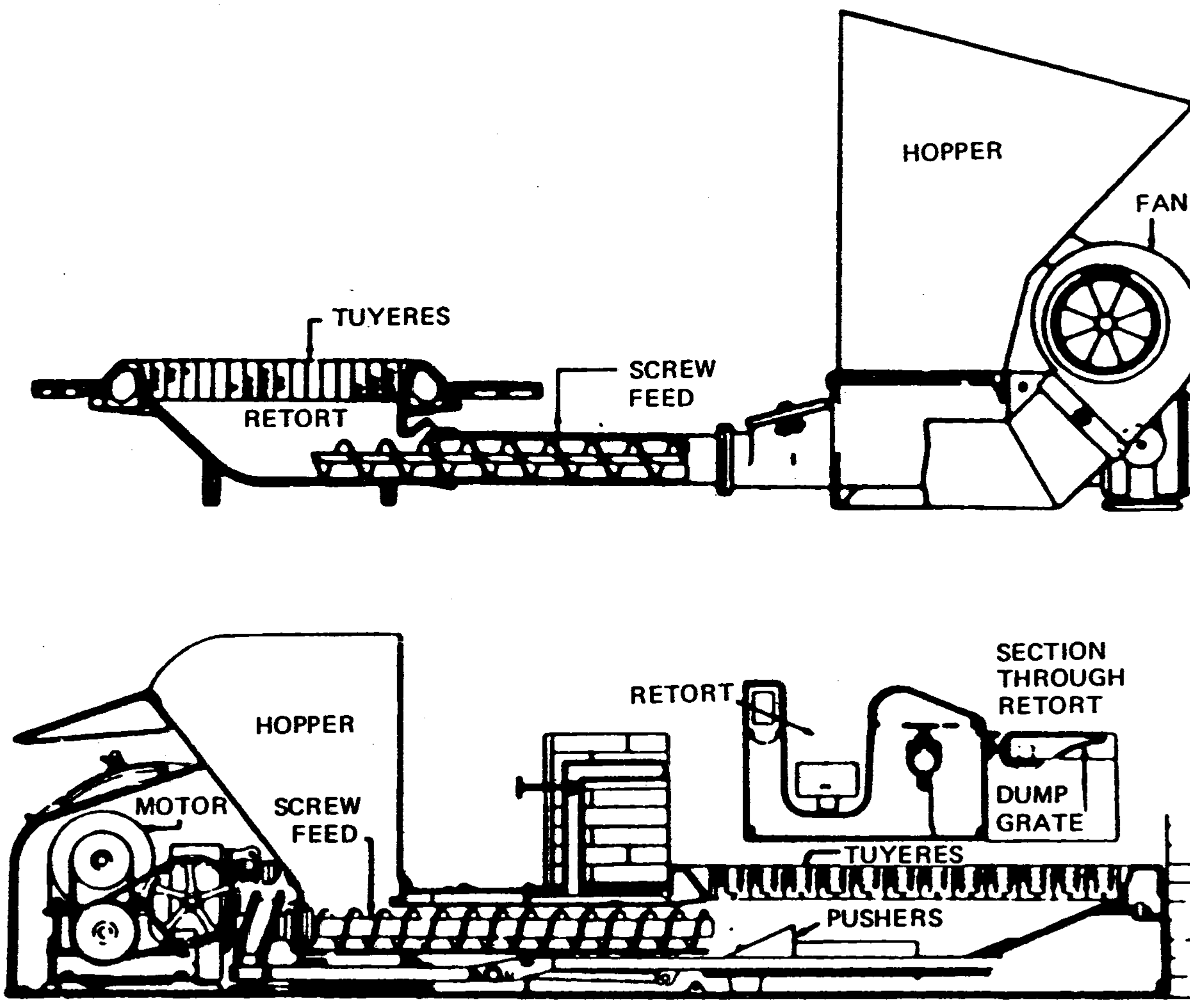


FIGURE 2–30. UNDERFEED STOKER

and are surrounded by either dead plates or dump plates. Dump plates are ordinarily made to permit air to pass through them. Tuyere blocks may be high and slope away from the retort, or recessed below the dead plate. They may be of either stationary or movable design.

(4) **Combustion Air Fan.** Centrifugal or axial fans are used to supply air to a windbox under the retort and to overfire air ports. The windbox may be divided into zones to permit better control of combustion air. The windbox may be divided into zones to permit better control of combustion air. The volume of the air supplied is controlled by inlet or outlet control dampers on the fan. Air flow should be controlled automatically to correspond to changes in the firing rate. Methods of control are discussed in paragraph 2-26.

c. **Spreader Stokers.** Spreader stokers combine some of the best features of hand- and pulverized-coal-firing methods. This method of coal feed permits smaller particles to burn in suspension in the furnace, approximating the action of pulverized-coal firing. The reminder of the coal is deposited on top of the burning coal, as in hand firing. Other similarities to pulverized-coal firing are the presence of fly ash in the flue gases, the wide range of fuel which can be handled, and responsiveness to rapid load fluctuation. Spreader stokers are not affected by the caking or non-caking properties of coal to the same extent as other types of stokers, and they can handle coal ranging in size from dust to about 1¼ inches. The furnace volume to permit fines to be burned in suspension is usually about 50 percent larger than that required for an underfeed stoker. The depth of the grate is limited by the ability of the stoker to spread coal evenly, and its width is limited by the width of the boiler; however, several stoker units can be placed side by side to provide the necessary capacity. Spreader stokers with combined traveling grates have been applied to boilers with capacities up to 400,000 pounds of steam per hour. Although the ability to burn inexpensive coal screenings is one of the chief advantages of spreader stokers, fly-ash emissions increase greatly as the percentage of fines is increased. Thus, under most conditions, spreader stokers require some type of dust collectors. All spreader stokers operate with comparatively thin fuel beds, are sensitive to load changes, and are well adapted to regulation by automatic combustion-control equipment. The thin fuel bed is a decided advantage in following fluctuating loads. Figure 2-31 illustrates a power dumping type spreader stoker. The principal elements of a spreader stoker are described below.

(1) **Feed Mechanism.** The feed mechanism consists of the feeder and the spreader. The spreader is constructed with either an underthrow or overthrow rotor. An overthrow rotor receives the coal directly and throws it into the furnace. An underthrow rotor picks coal out of a circular tray and throws it into the furnace. Figure 2-32 illustrates an underthrow rotor. The paddles (rotor blades) are usually set in either two or four rows around the rotor, with those in one row twisted at an angle to throw the coal to the right, and those in the next arranged to throw it to the left. In some designs, the paddle is curved to provide uniform crosswise distribution. An oscillating plate or ratchet-driven roll feeder is used to supply coal to the rotor. The rate at which coal is fed is regulated by varying the length of the stroke of the oscillating plate or the speed at which the roll is turned. Speed or position adjustments are also provided to regulate the distribution of fuel along the length of the grate. The feeder mechanism, the grates, and the air supply are usually constructed to operate as a unit. The feeders are usually driven from a single line shaft, with each having its own drive gearing. When dumping grates are used, sections pf the fire can be cleaned alternately by shutting off the fuel to one feeder and allowing the fuel to burn out in that section of grate before dumping. The variable speed-driven mechanisms are similar to those found on underfeed stokers. Variable speed motors often replace the mechanical gearing to drive the individual feeder and distribution shaft on newer designs.

(2) **Overfire Air Fan.** A separately driven centrifugal fin is provided to supply overfire air necessary to maintain proper fuel and air mixing and complete combustion. A portion of the overfire air may also be used to cool the feed mechanism and aid in distribution of the coal.

(3) **Cinder Reinjection System.** Since the spreader stoker burns a significant percentage of the coal in suspension, carryover of unburned coal is common. To improve boiler efficiency by reducing this unburned carbon loss, the fly ash and coal can be collected in a mechanical ecollector at the boiler outlet and put back into the boiler furnace. This is done by use of a cinder reinjection fan and aspirator which picks up the fly ash and coal and pneumatically conveys it back to the furnace via special piping and reinjection ports.

(4) **Grates.** Stationary, dumping, vibrating, and traveling grates may be used with a spreader stoker installation. Traveling grates are most commonly used on modern installations. Provision is made under the grates for proper air distribution and ash collection. Figure 2-10 illustrates a spreader stoker with traveling grate installation.

(5) **Combustion Air Fan.** As with all stokers, combustion air under pressure is neded to ensure complete and efficient combustion and control. Inlet or outlet dampers are provided to control the air flow rate.

d. Traveling Grate and Chain Grate Stokers. These type of stokers consist of an endless belt-type grate which moves slowly and conveys the burning coal from the feed end

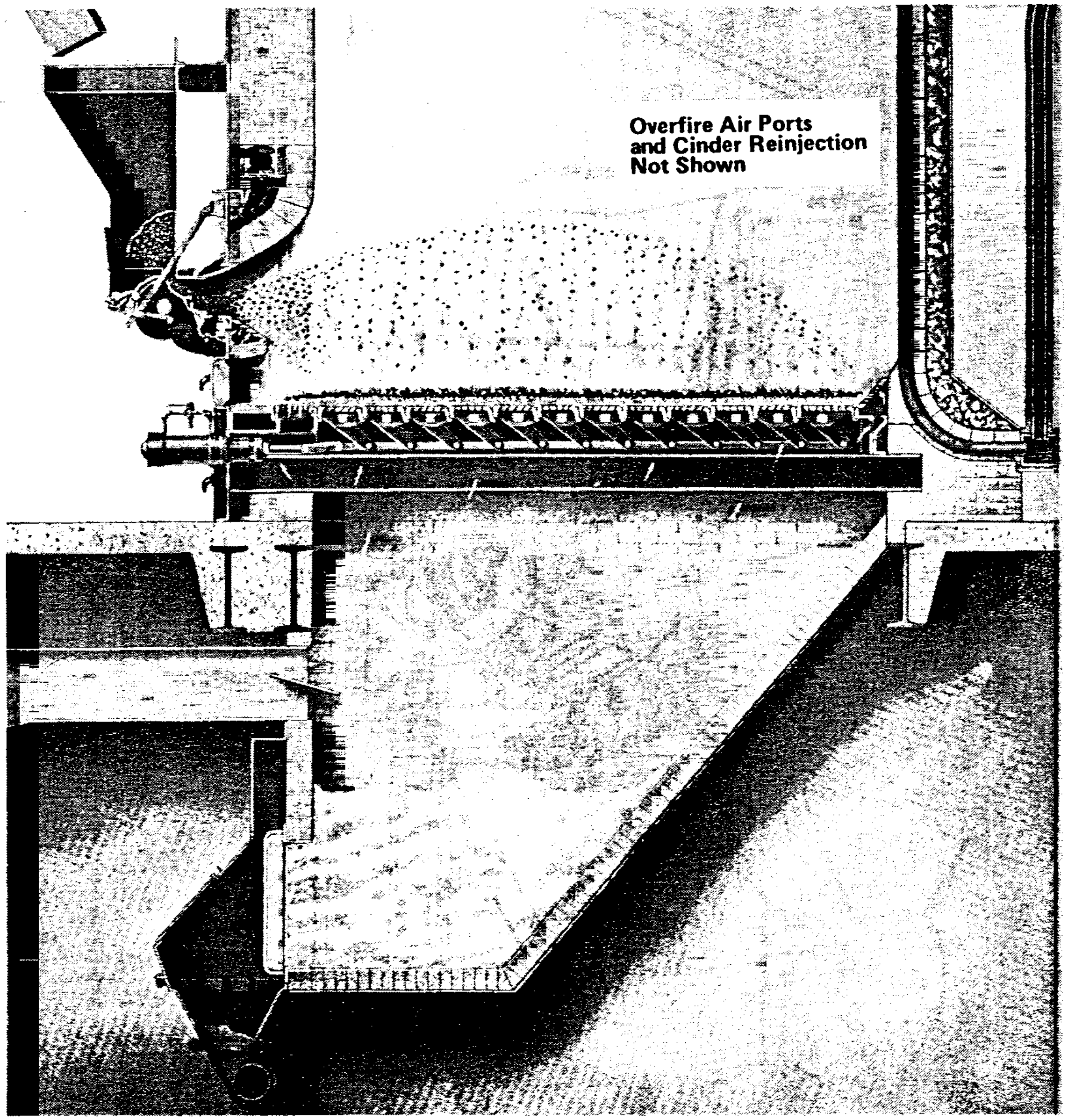


FIGURE 2-31. POWER DUMP GRATE
SPREADER STOKER

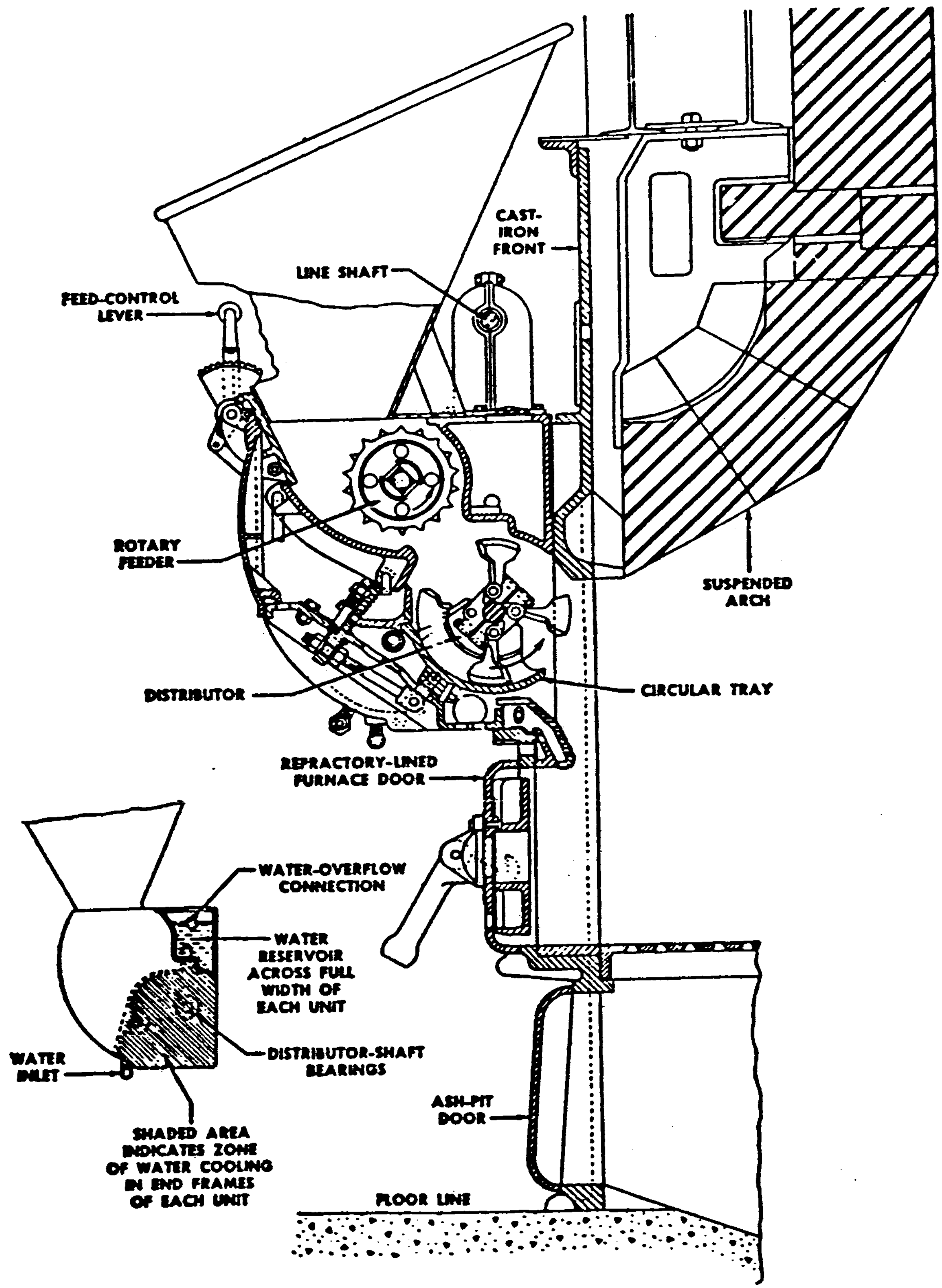


FIGURE 2-32. UNDERFEED SPREADER

to the ash discharge end of the stoker. With chain grate stokers, the links are assembled so that as they pass over the rear idler drum, a scissor-like action occurs between the links. This action helps to break loose clinkers which may adhere to the grate surface. Traveling grate stokers do not have this scissor action and therefore are not normally used with clinkering coals. Figure 2-33 illustrates a traveling chain grate stoker. Traveling or chain grates may be used with spreader feeders discussed above, or the coal may be placed directly on the stoker, as described below.

(1) **Feed Mechanism.** A hopper on the front of the stoker has an adjustable gate which regulates the depth of the fuel bed. The rate of feeding coal to the furnace is regulated by changing the speed at which the grrate travels. The amount of ash carryover from the furnace is kept to a minimum with this feeding method, and fly-ash injection, typical of spreader stokers, is not required. Figure 2-33 illustrates the overfeed of coal onto a chain grate.

(2) **Combustion Air.** The space between the grates is divided into zones and the flow of air to each of these zones is contolled by dampers. This is necessary if uniform combustion is to be attained, because the resistance of the fuel bed to the flow of air decreases as the grates nove to the rear. It would be practically impossible to get proper air distribution if these zones were not provided. Overfire air is also provided to complete the combustion of volatiles driven off from the fuel bed.

e. Vibrating Stokers. In this type of stoker the grates are inclined at an angle of about 14 degrees. Coal is fed from a hopper at the front of the furnace. The fuel bed is progressed by intermittnet grate vibrations. Ash is discharged over the end of the grate (reference figure 2-34). The furnace water tubes are positioned under the stoker grates to cool the grate bars, and air compartments are provided to control combustion air. Overfire air is generally provided at two elevations. The firing rate is controlled by adjustment of a hopper feed gate, frequency of grate vibration, combustion air dampers, and overfire air dampers.

f. Pulverized Coal. Pulverized coal firing requires the operation and maintenance of pulverizers. Historically, it has not been economical to install pulverized coal firing systems on boilers with a steam flow of less than 100,000 pounds per hour, and they are uncommon in Army Central Heating Plants. For further information on pulverized coal systems, refer to Navy Manual MO-205, Volume One, Sections 19 and 20.

g. Fluidized Bed. Fluidized bed combustion is a relatively new method of burning coal while complying with sulfur dioxide emission regulations. In fluidized bed combustion the coal is introduced into a bed of limestone or sand particles which is kept in a fluidized state by a flow of high pressure air from FD fans. Combustion takes place in the bed. The sulfur in the fuel combines chemically with the limestone in the bed, forming calcium sulphate and calcium sulphite which can be removed with the ash handling system, eliminating the need for scrubbers to clean the flue gases. The main advantage of the fluidized bed boiler is thus its ability to control sulfur dioxide emissions. However, it also has the ability to burn a wide variety of fuels as discussed below. The disadvantages of fluidized bed boilers are the added electrical operating costs associated with the larger combustion air fans necessary for fluidizing the bed, higher particulate and unburned carbon carryover from the furnace, and high initial cost.Figure 2-35 illustrates a fluidized-bed fire tube boiler. Fluidized-bed water tube boilers are also available. Note that a baghouse or precipitator is required for particulate control.

h. Fuel Characteristics and Specifications. The following paragraphs provide general guidelines on the types of coal which arc applicable to the various firing methods. There is, however, much overlap in these guidelines, and the equipment manufacturer or tother combustion expert should be consulted if a change in fuel type is considered.

(1) **Underfeed Stokers.** In practical applications, fuels ranging from lignite to anthracite have been burned successfully on single retort underfeed stokers. However, this type of stoker is most widely used for Eastern caking and mildly caking bituminous coals and many of the Midwestern free burning coals, especially those having an ash fusion temperature sufficiently high for successful utilization in the relatively thick fuel beds that characterize underfeed burning. For satisfactory stoker operation, coal sizing is as important as coal analysis. The size of coal best suited for single retort stokers is that designated commercially as 1 inch to 1½ inch nut and slack, preferably containing not more than 50% slack. Slack is defined as coal of a size that will pass through a ¼ inch round-hole screen. For multiple retort underfeed stokers the id al coal should vary in size from 2 inch to slack, with not more than 50% slack. The volatile content should preferably be between 20 and 30%; the ash content should range between 6 and 8%, and the ash softening temperature should be above 2400 F in a reducing atmosphere. Iron content of the ash should be not more than 20% as Fe_2O_3 for this range of softening temperatures and not more than 15 percent if the softening temperature is between 2200 and 2400 F.

(2) **Spreader Stokers.** Spreader stokers were developed to burn the lower grades of coal, but they are capable of handling all ranks from semianthracite to lignite, plus numerous waste and byproduct fuels. As might be expected, spreader stoker performance is best when quality and sizing

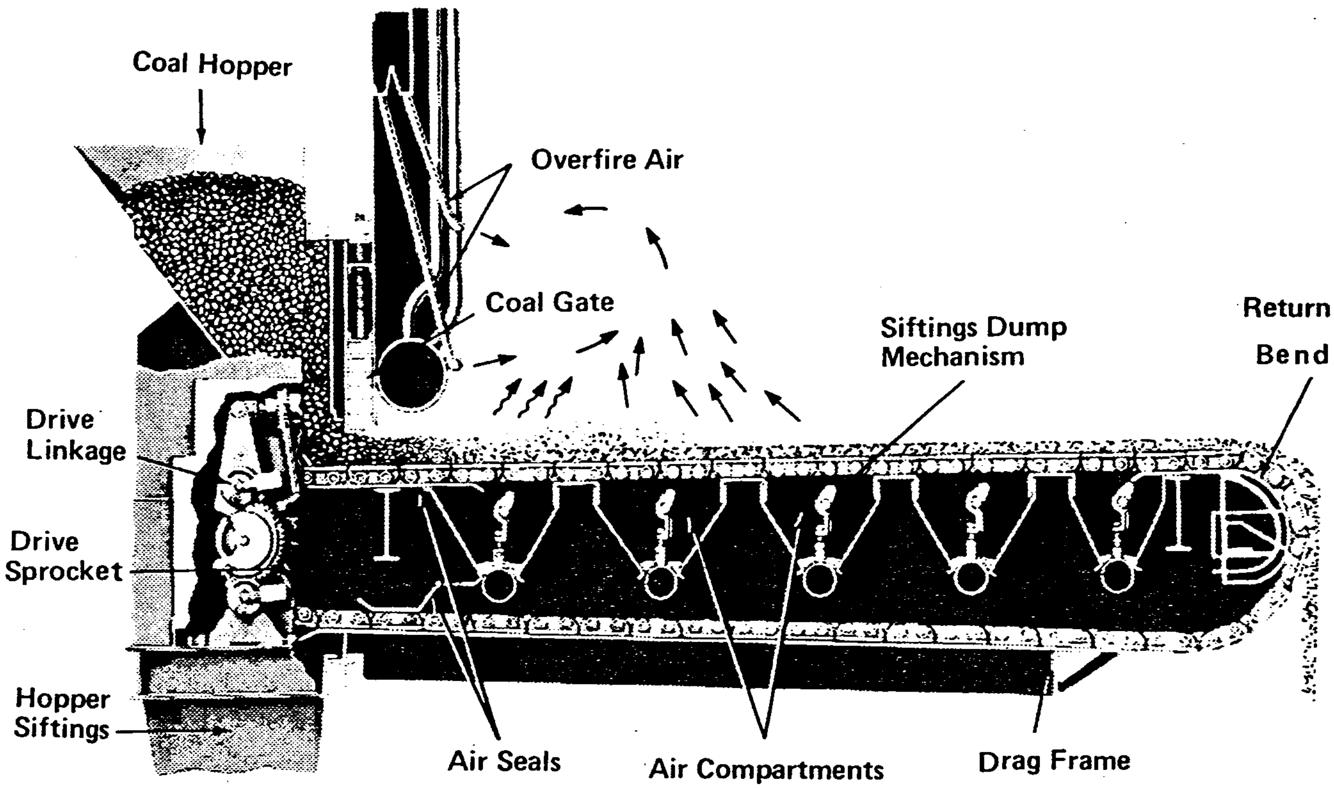


FIGURE 2-33. TRAVELING CHAIN GRATE STOKER

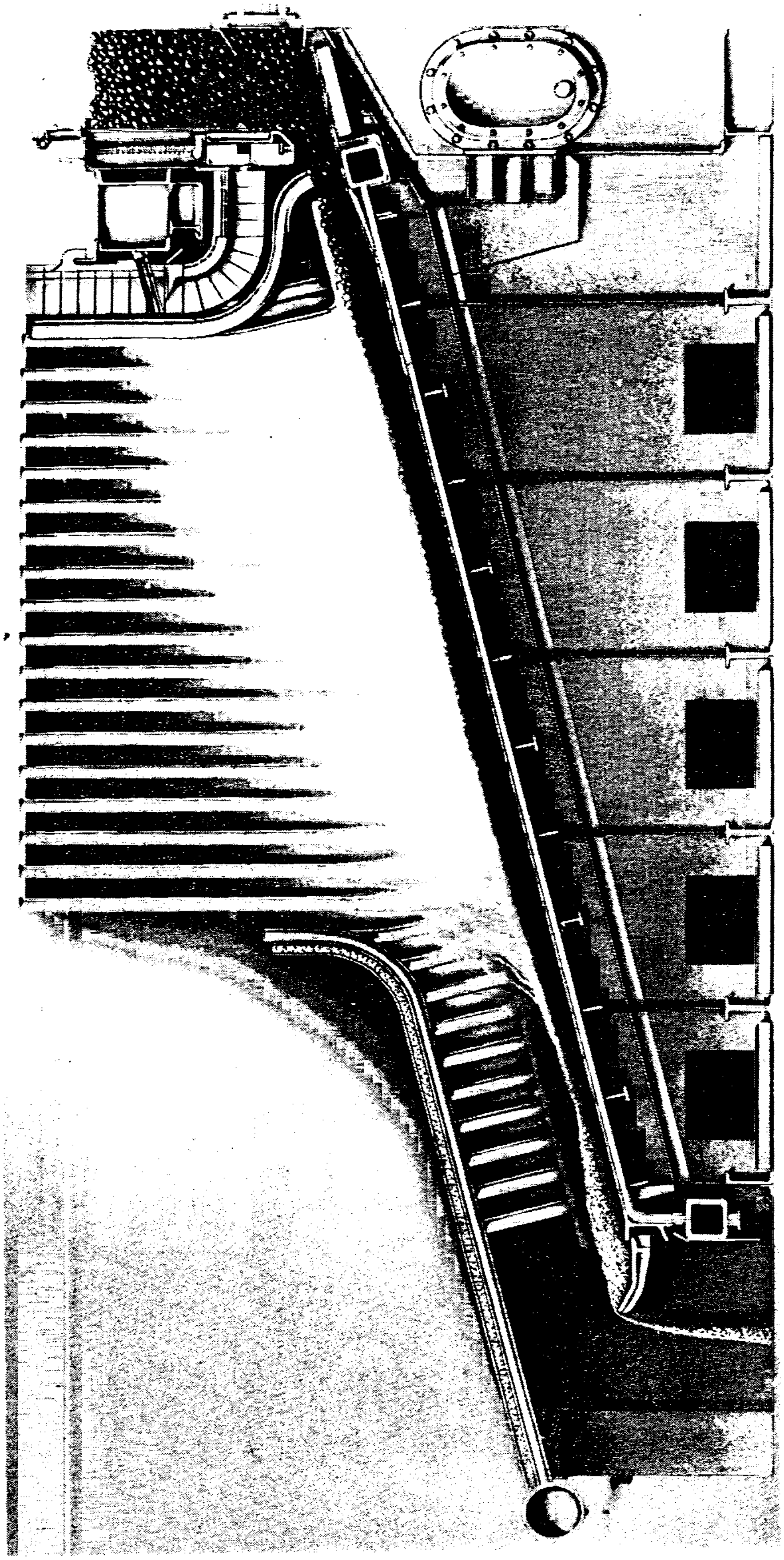


FIGURE 2-34. VIBRATING GRATE STOKER

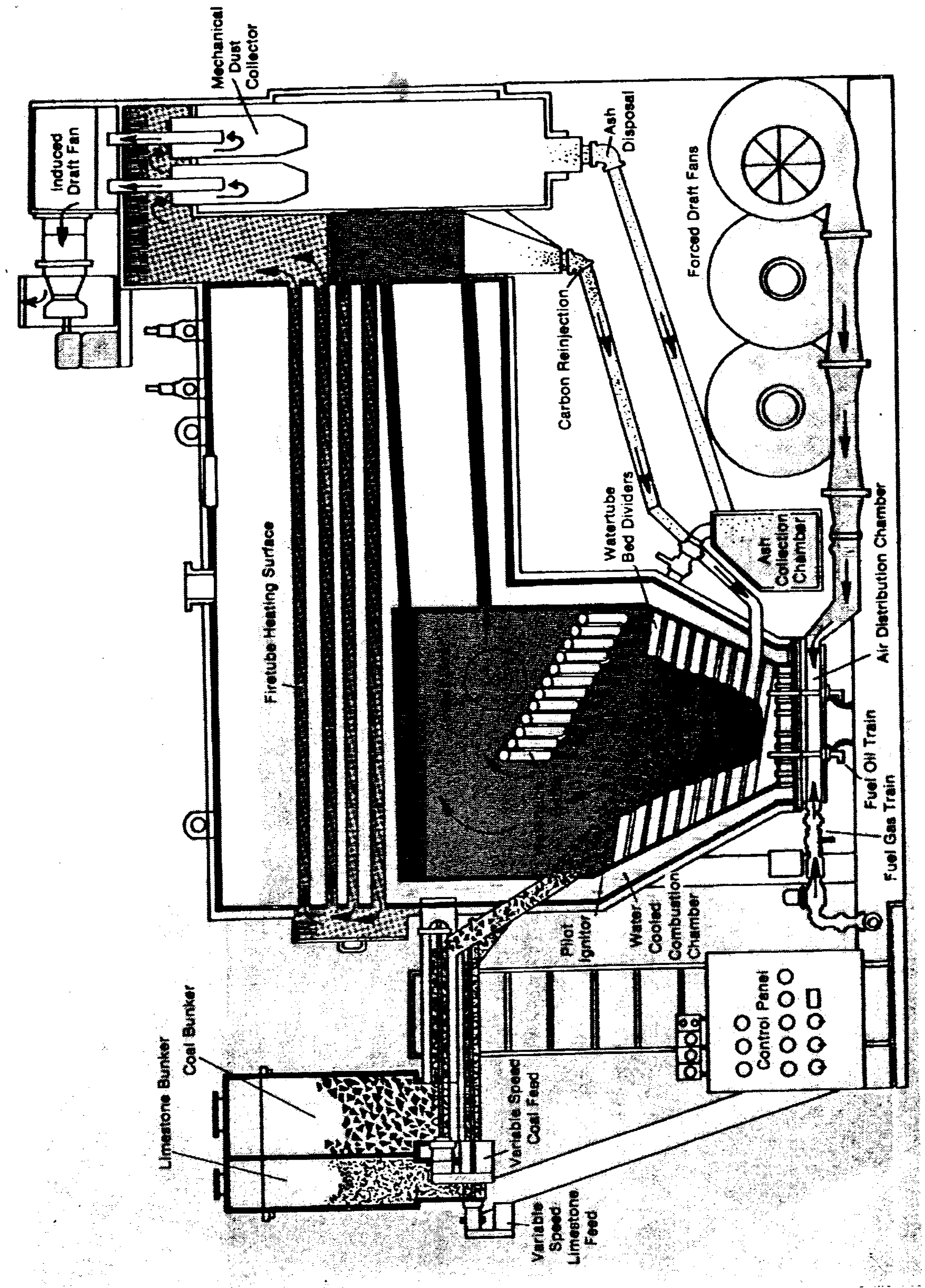


FIGURE 2-35. FLUIDIZED BED FIRE TUBE BOILER

are good.The thin, quick burning fuel bed requires a relatively small size fuel. The spreader stoker will burn fuel ranging from slack or carbon, all through ⅛ or ¼ inch screen, to 1¼ or 1½ inch nut and slack. Considerable range in size content is necessary for satisfactory distribution, and if there is a good balance between coarse and fine particles the burning rate and ash bed thickness are practically uniform over the entire grate surface.

(3) **Traveling Grate and Chain Grate Stokers.** The fuels most widely used on traveling grate stokers are anthracite, semianthracite, noncaking or free-burning bituminous coal, subbituminous coal, lignite and coke breeze. Some bituminous coals of the caking type may be burned on traveling grate stokers if the coal is of an optimum size, has been allowed to weather, and is tempered to approximately 15 percent moisture. Coal sizing for traveling grate stokers may be related to the ASTM Classification of Coal by Rank (D-388) as shown in table 1-1. For anthracite (Rank I-2), the size of No. 3 buckwheat (barley) should be all through 3/16 inch round hole screen and not more than 20 percent through 3/32 inch screen; No. 4 buckwheat should pass through a 3/32 inch round hole screen with not more than 10% through a 3/64 inch creen and not more than 1% through a 100 mesh screen. For coals of ASTM Ranks II-4, 5, III-1, 2,3, and IV-1, 2 the size should be 1 inch nut and slack with not more than 50% slack through a ¼ inch round-hole screen and tempering to 15% moisture. For friable coals of ASTM Ranks II-1, 2, 3, the sizing should be 1 ¼ or 1½ inch nut and slack with not more than 50% slack through a ¼ inch round screen. For nonfriable coals of ASTM Ranks II-1,2,3, the sizing should be ¾ inch nut and slack with not more than 50% slack through a ¼ inch round-hole screen. If coke breeze is burned on traveling grate stokers, it should contain 8 to 10% moisture and not less than 1% volatile matter; the entire quantity should pass through a ⅝ inch round mesh with not more than 50% or less than 25 percent through a ⅛ inch round-hole screen.

(4) **Vibrating Grate Stokers.** The water-cooled vibrating grate stoker is suitable for burning a wide range of bituminous and lignite coals. Even with coals having a high free-swelling index, the gentle agitation and compaction of the fuel bed tends to keep the bed porous without the formation of large clinkers generally associated with low ash-fushion temperature coals. A well-distributed, uniform fuel bed can be maintained without blow holes or thin spots.

(5) **Fluidized Bed.** Fluidized bed boilers may be used o burn almost any fuel, including not only bituminous and anthracite coals but also lignite, refuse, wood, and various solid waste fuels.

2-19. COAL-HANDLING EQUIPMENT.

A great many types of coal-handling equipment with capacities ranging from a few tons to several hundred tons per hour are available. The kind of equipment selected is determined by such factors as size of plant, total amount of fuel to be burned, method of receiving the coal (rail, truck, or water), regularity of delivery, kinds of coal available, and relative locations of the plant and storage areas. It is usually advantageous to keep a certain amount of coal in storage, in case deliveries are delayed for any reason. The amount of coal stored depends on the rate at which it is burned, space available for storage, and frequency of delivery. The quantity stored should normally be sufficient to operate for 90 days or longer at peak demand.

a. Storage. Coal lmay be stored in covered bins or bunkers, in silos, or in the open. Only relatively small amounts can be stored in bunkers and silos. The amount that can be stored on the ground is limited only by the space and coal handling equipment available. If coal is to be stored on the ground, the selected area should be prepared to reduce loss of fuel due to mixing with foreign material. The site may be leveled and firmly packed, stabilizing materials may be used, or a concrete or asphalt surface may be laid. Silo storage is divided between live and dead storage. The dead storage in silos should be shifted at least once per month. Where obvious heating occurs, shifting of dead storage should be as often as required to minimize spontaneous heating and to avoid fires. For additional information, see TM 5-675 concerning handling, storing, and sample preparation.

b. Coal Handling in Plant. Figure 2-36 illustrates a system typical of those found in Army Central Heating Plants. It includes the following major components: track or truck hopper, feeder, bucket elevator or conveyor, bunker or silo, and coal weighing device.

(1) **Hoppers.** Hoppers receive coal from trucks or coal cars and deliver it to a feeder or conveyor system. Hoppers usually have grates made of steel rods or bars to prevent passage of oversized material which could plug or damage the conveying equipment.

(2) **Feeders.** Manytypes of feeders are available to convey and regulate the flow of coal from the hopper to the bucket elevator or other parts of the system. Apron feeders and flight feeders are continuous chain-type feeders which are often used. Final selection is dependent on the particular site characteristics.

(3) **Bucket Elevators.** A bucket elevator consists of an endless chain, twin chains, or belt to which buckets are attached. It is used to lift coal vertically. The three most common types of bucket elevator discharges are centrifugal, perfect, and continuous (reference figure 2-

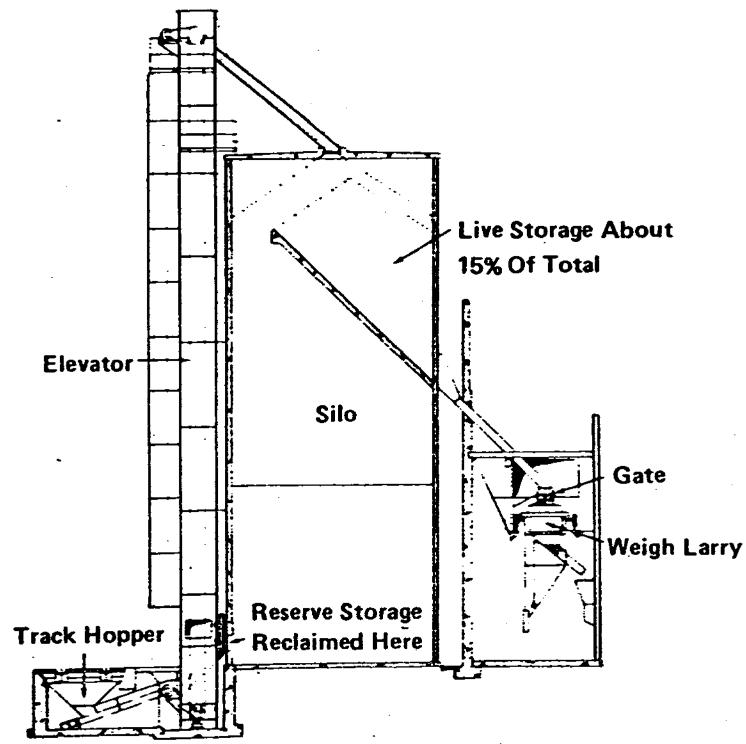


FIGURE 2-36. COAL HANDLING SYSTEM

37). Elevator boots are provided with clean-out doors for removing dropped coal. Some bucket elevators can also convey coal horizontally. Belt conveyors and drag-type flight conveyors are other effective devices for delivering coal to bunkers.

(4) **Bunkers and Silos.** Bunkers and silos provide covered storage of the coal. Bunkers are made of steel and are often lined with a protective coating to minimize corrosion and abrasion. Hopper bottom and discharge gates are provided to remove coal from the bunker. Silos are constructed of either steel or concrete and are often provided wilth live storage sections and reserve storage sections.

(5) **Coal Weighing.** A knowledge of the quality and quantity of coal used is essential for efficient operation of a boiler plant. No standard method of weighing coal can be prescribed, since many types of equipment are available for doing the job manually or automatically. Coal may be weighed directly with weighing equipment, or indirectly with equipment which measures its volume. Weighing equipment ordinarily consists of automatic or semiautomatic weigh larries. As shown in figure 2-38, a weigh larry consists of a framework which supports a hopper mounted on scale beams. The framework can be moved over the various bunkers. The coal hopper of the larry is filled and the weight determined and recorded. The larry is then moved to the desired stoker hopper and dumped. Coal scales which weigh coal automatically are also available. One type of scale consists of three major assemblies: a belt feeder, a weigh hopper with bottom dump gate, and a weigh lever with controls. A mechanical register is provided to record the amount of coal delivered. A belt feeder transfers the coal into the weigh hopper until the weigh lever is balanced. The weigh hopper is then dumped and the cycle is repeated.

2-20. ASH-HASNDLING EQUIPMENT.

Ash typically requires removal from several collection points in the boiler. Ash that is removed directly from the furnace or stoker is termed "bottom ash" and may be in hard, agglomerated clinkers. Ash that is removed from various dust collection points is termed "fly ash" and tends to be light, fluffy, and relatively free flowing. All the ash is generally handled together and disposed of in a permitted landfill, especially on small systems. Depending on individual circumstances, it may be desirable to segregate the bottom and fly ash and handle them separately. This could be advantageous, for instance, if a commercial market existed for one of the products. (Fly ash may be used in the manufacture of concrete; bottom ash may be used as a winter road treatment, etc.) Medium-size and large plants generally employ complete ash disposal systems, while small plants may use simpler and less automatic equipment. The three general types of ash-handling systems are pneumatic, hydraulic, and mechanical. Combinations of these three systems are often used.

a. **Pneumatic Ash Handling.** Figure 2-39 illustrates a vacuum-type pneumatic ash-handling system. In this illustration, the vacuum is created by a steam exhauster; however, motor-driven vacuum pumps are also available. Intake hoppers provided at desired locations admit the ash to the system. One end of the ash-conveying line is open, and the suction created by the exhauster causes a rapid flow of air through the line. Dry ash is admitted to the primary and secondary ash receivers, which are equipped with counterbalanced drop doors. A timer limits the period of operation to short cycles to permit dumping the ashes into the silo. As the system goes into operation the negative pressure in the receivers closes and seals the drop doors. At the end of each cycle, the doors swing open when the pressure is equalized, and drop the ashes into the silobelow. The air washer condenses the incoming steam from the exhauster, washing out ash and dust particles entrained in the air stream. Clean air is thus exhausted to the atmosphere. The mixture of water and dust passes to a sump, where the dust settles and the water is drawn off to waste. It is necessary to clean the sump periodically to prevent clogging the sewer. An exhaust silencer is available for this system where desired. An unloader is usually provided and consists of an inclined revolving drum containing water sprays which wet the ashes as they are discharged from the bottom of the silo. Vacuum systems are limited in the distance which they can move ash effectively, and pressurized pneumatic systems or combination vacuum/pressure systems are available if the conveying distances become too great. Pneumatic systems are most commonly used for conveying fly ash but are also occasionally used for bottom ash on small systems.

b. **Hydraulic Ash Handling.** Figure 2-40 illustrates a hydraulic ash-handling system. This is a pressure velocity system in which the otivating force is provided by a series of high-pressure water jets. When the system operates, the ash is taken from the ash jet hopper beneath the boiler. Sprays and water jet nozzles flush the material out of the hopper and through a grid which retains any large clinkers for breaking. Some systems are equipped with clinker grinders. The ash is then jetted through an abrasion-resistant sluice gate to a sump pit or a landfill. The fly ash and dust are aspirated pneumatically from the dust hoppers by water jet exhausters and passed through an air separator where the air is collected and vented to the atmosphere. Finally, the mixture of fly ash, dust, and wateer is discharged through the sluice gate to the sump pit or landfill. Hydraulic systems are normally used for bottom ash conveying. They are used infrequently on new

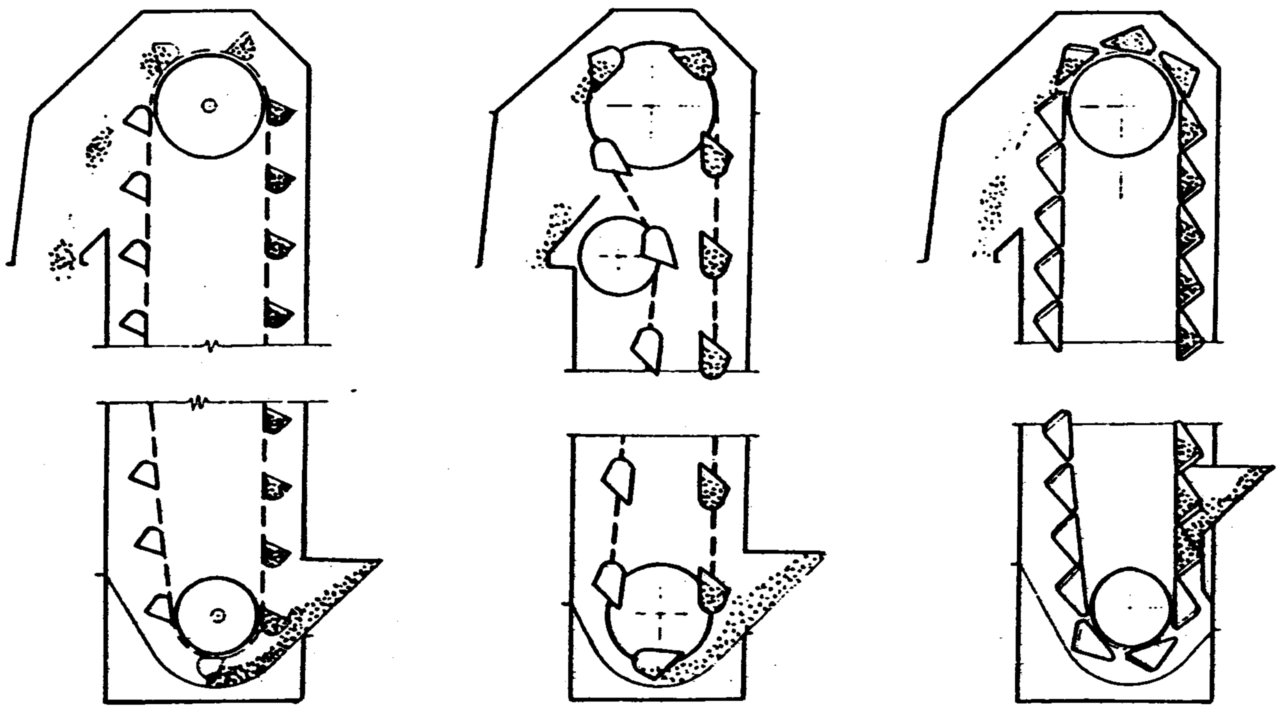


FIGURE 2-37. TYPES OF BUCKET ELEVATORS

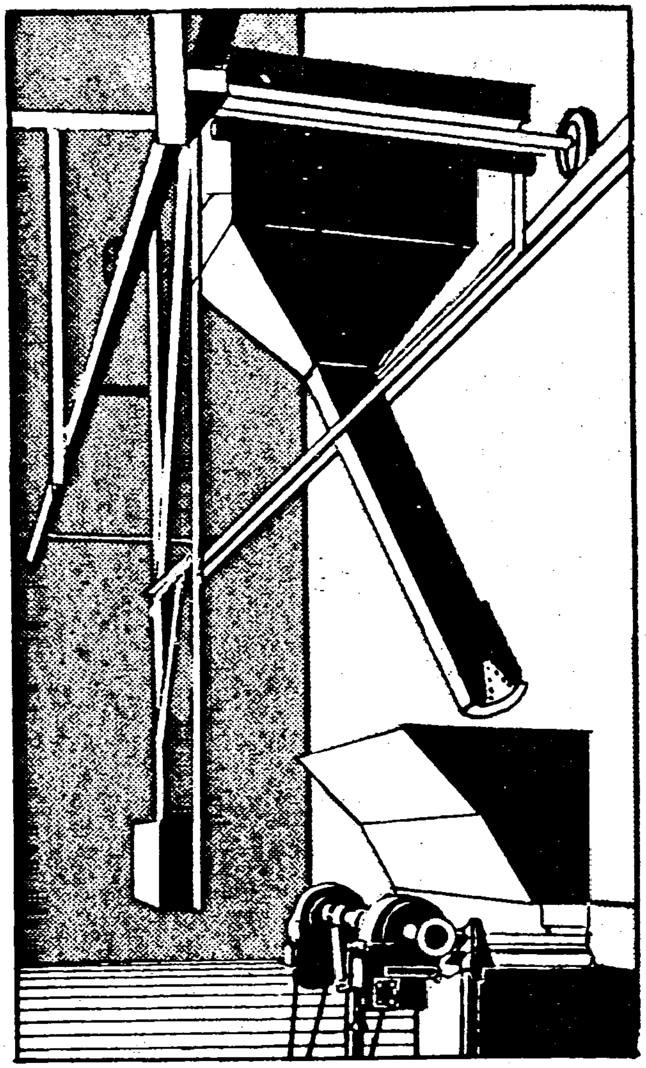


FIGURE 2-38. WEIGH LARRY

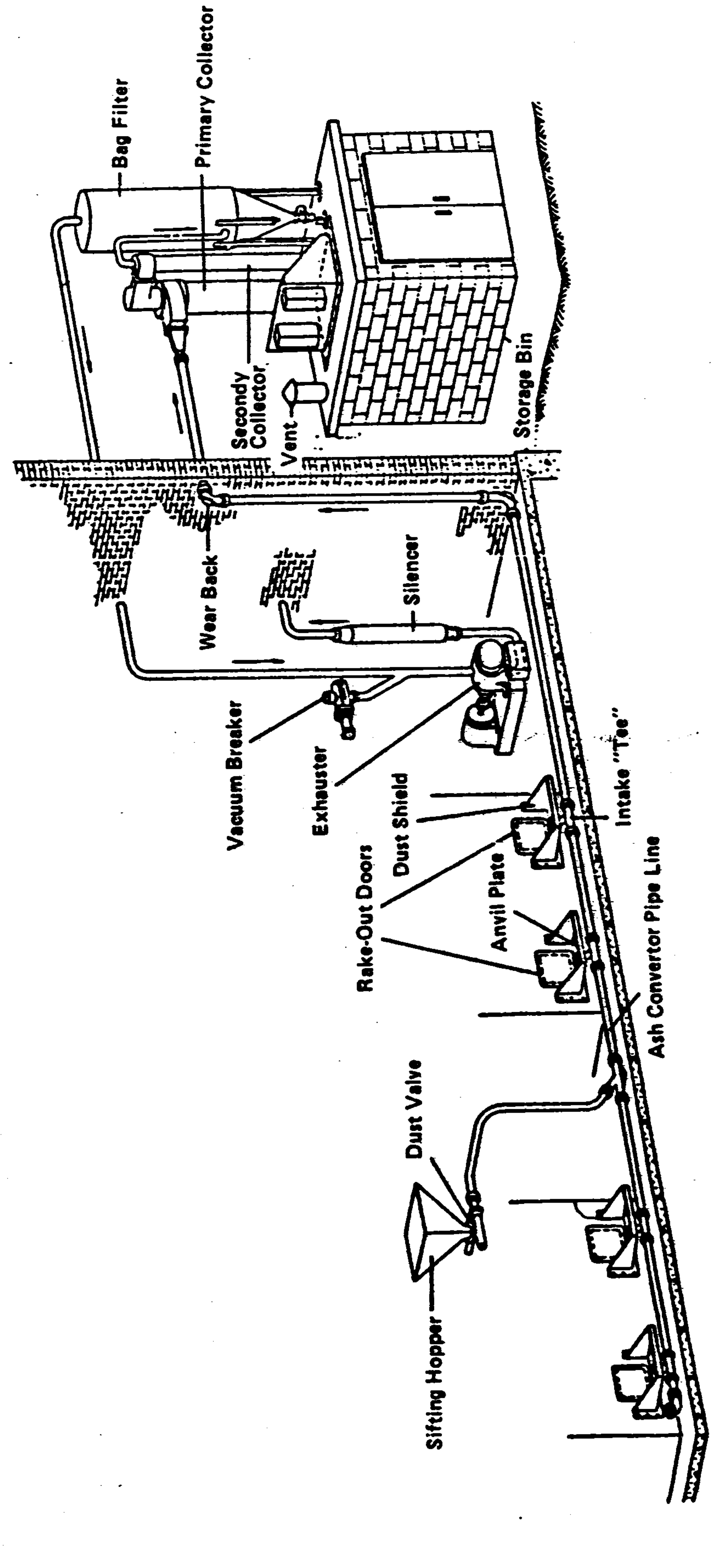


FIGURE 2-39. PNEUMATIC ASH HANDLING SYSTEM

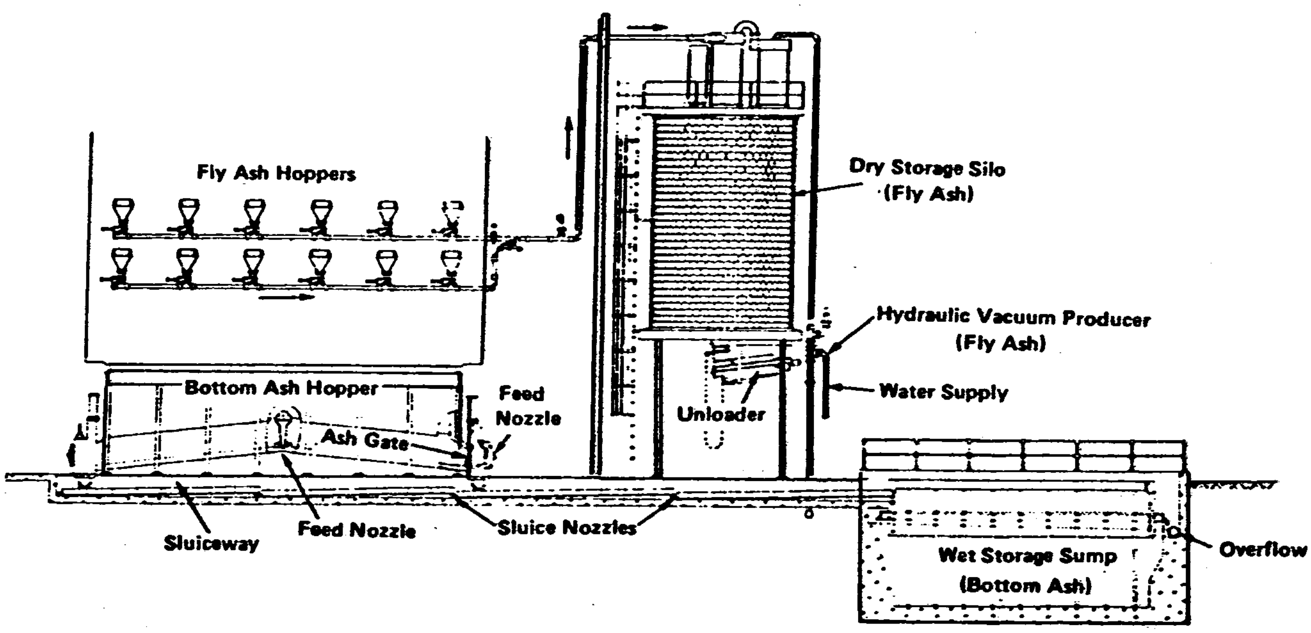


FIGURE 2-40. HYDRAULIC ASH HANDLING SYSTEM

installations due to environmental and water usage regulations.

c. Mechanical Ash Handling. Drag, screw, and bucket conveyors can be used to move ash from the boiler ash pits to storage bins, silos, or containers. Mechanical systems are used primarily with small stoker fire boilers, and may be utilized for either bottom ash or fly ash.

2-2l. OIL-FIRING EQUIPMENT.

Oil has a number of advantages over coal when used to generate steam or hot water: the cost of fuel handling is lower, less labor is required for operation and maintenance, less storage space is required, the initial cost of the oil system is lower, and higher efficiencies are possible. In addition, oil does not normally deteriorate in storage; it is a clean-burning fuel and is easy to control. A disadvantage of oil is the greater danger of explosions which leads to more elaborate flame safety ontrols, and its cost, which is two or three times higher than coal on a heating value basis. Refer to paragraphs 1-4b and 1-8 for a more detailed discussion of fuel oil and the combustion process and to table 1-3 , which presents the physical properties of common grades of fuel oil. The operator should be familiar with the fundamental principles of combustion to make best use of this concentrated and valuable fuel.

a. Types of Oil Atomizers. Burners in Central Heating Plants utilize three types of atomizers: atomizers using steam or air, pressure atomizers, and rotary cup atomizers. The purpose of atomization is to break the fuel into fine particles that readily mix with combustion air. The fuel then burns with a clean hot flame, being vaporized and oxidized by the resulting combustion before cracking takes place. In pressure atomizing burners the fineness of spray increases as pressure increases and as viccosity is lowered. When No. 6 oil is burned, a pulsating flame may result if viscosity is reduced to a point where the preheat temperature tends to vaporize the fuel. The burner manufacturer should recommend a proper viscosity range at which to operate. Proper preheating of oil will be discussed in paragraph 3-17.

(1) **Fluid Atomizers.** Fluid atomizers use either steam or air to break the fuel oil into a fine mist. Steam atomizers operate by mixing the oil and steam inside the atomizer tip under pressure. As the steam and oil mixture leaves the tip, the steam rapidly expands, breaking the oil into small droplets to begin the combustion process. Figure 2-41 illustrates a steam atomizer. Steam is supplied to the atomizer at a pressure of between 10 and 20 psi above the oil pressure. Under normal conditions, a steam atomizer uses approximately one-tenth pound of steam to atomize one pound of oil. This amounts to about 2/3 of 1 percent of the boiler steam output. Some modern atomizers use as little as 0.03 pounds of steam while older designs may use more steam. Compressed air may also be used in place of steam to atomize oil. An air atomizer uses energy developed by the air compressor to replace energy in the steam generated in the boiler. Air atomizers are commonly used when steam is not available, on smaller boilers generating less than 20,000 pounds of steam per hour, and for firing more easily atomized oils, such as No. 2 and No. 4 grades. Air atomizers are often used for cold startup of a boiler, then replaced by steam units as the plant pressure builds up. Both steam and air atomizers are effective when used with a good burner to control combustion air mixing. Automatic control of firing rate is possible over a range of 15 to 100 percent of capacity.

(2) **Pressure Atomizers.** Pressure atomizers use pressures of 600 psig or more to accelerate the oil into the furnace through the atomizer tip. The oil is spun inside the tip and leaves as a cone of oil which thins out and breaks apart into fine droplets for combustion. The advantage of pressure atomizers is the simplicity of the system. The disadvantages are the high pressure required and the fact that turndown range is limited to 75 to 100 percent of capacity if effective atomization is to be maintained. This type of atomizer is also sensitive to oil viscosity, and the small passages in the atomizer tips tend to clog and wear. Pressure atomizers are not frequently used on modern Central Heating Plants. (3) Rotary Atomizer. The rotary atomizer uses the energy from a spinning cup and primary air from a small fan (refernce figure 2-42). A thin cone of oil is spun off the end of the cup and, aided by the primary air, thins out and braks apart into fine droplets. Rotary atomizers can be fairly effective when combined with burners using forced draft fans. Natural draft rotary atomizer burners as developed in the 1930s do not compare favorably with modern forced draft burners and, in general, rotary atomizers do not have any significant advantages over fluid and pressure types. They have the disadvantages of limited capacity and electric horsepower requirements for driving the rotary cup and the primary air fan. They generally become uneconomical for boiler capacities above 20,000 pounds of steam per hour, and are seldom used in modern burners. Figure 2-42. Rotary Atomizer

b. Types of Burners. Once the oil is effectively atomized, the next step is to effectively mix it with the combustion air. Three general types of burners are available: register, low excess air, and package burners. All of these burners incorporate an igniter for automatic light-off and provision to mount flame scanners to prove igniter and/or main flame. Effectiveness of a burner is measured by its ability to complete combustion of the fuel with a minimum of excess air throughout the firing range. Excess air levels at 100, 75, 50, and 25% load should be determined when

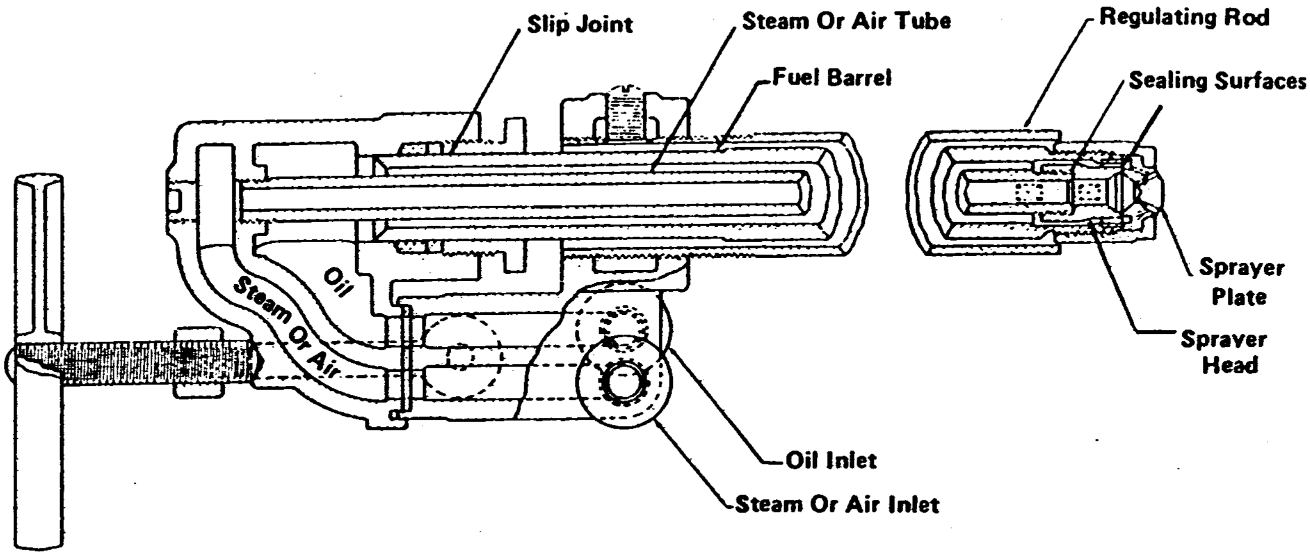


FIGURE 2-41. STEAM ATOMIZER

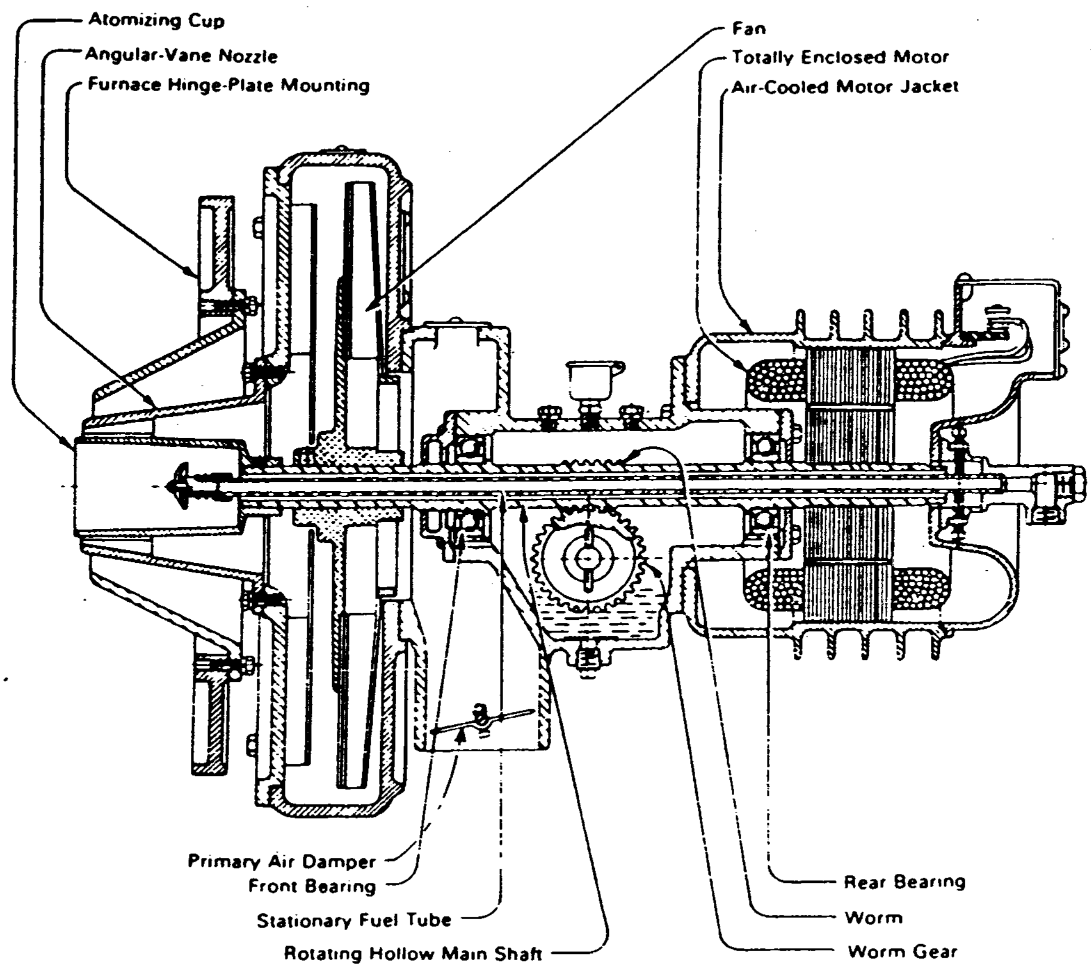


FIGURE 2-42. ROTARY ATOMIZER

evaluating burner effectiveness. Reference paragraph 3-34 and table 3-1 for more information.

(1) **Register Burners.** Register burners are characterized by one or more circular registers which admit combustion air into the burner throat as illustrated in figure 2-43. An impeller is provided to protect the atomizer from the direct blast of the combustion air and to provide a zone to stabilize ignition. The refractory throat helps to control air flow and velocity, and the hot refractory helps to stabilize ignition by radiating heat back into the base of the flame. Adjustment of the air registers either initially or on a continuous basis with load swings helps to ensure that optimum air velocities are available for the combustion process. Register burners may be used with ambient or preheated air, oil atomizers, and/or gas burning equipment. Capacities from 10 to 200 million Btu/hr are common.

(2) **Low Excess Air Burners.** Low excess air (LEA) burners, as shown in figure 2-44, were developed to achieve lower excess air levels throughout the burner load range than is possible with register burners. A venturi section ensures uniform air flow at the burner outlet. An impeller is used to swirl a portion of the air into the atomized oil. The remainder of the air moves axially through the burner at a velocity designed to cause it to mix later with the fuel and impeller- swirled. air. The advantage of the LEA burner is its ability to operate at low excess air levels, with subsequent improvements in efficiency. The main disadvantage is a long, narrow flame which is not well suited for many furnace configurations. Very accurate combustion controls are needed to take advantage of this burners low excess air capability.

(3) **Package Burners.** Package burners include the forced draft fan and its air control damper, the oil and/or gas control valves, actuators, igniters, flame safety system, and combustion controls as a shop-assembled unit. Figure 2-45 illustrates an air atomizing oil- and gas-fired package burner. The cost and performance capability of package burners vary widely. Not all packages are suitable for every application. Every burner application requires careful consideration to ensure that the proper burner, controls and accessories are applied. Package burners should be capable of automatic start-up, shutdown, and modulating firing rate. Package burners are available for firing rate. Package burners are available for firing rates of several gallons to several hundred gallons per hour. Either register or low excess air type burners may be supplied as packages, and rotary, pressure, or fluid atomizers may be used.

2-22. OIL STORAGE AND HANDLING.

Above-ground and underground fuel storage tanks are available as illustrated in figures 2-45 and 2-46. These tanks are provided with some or all of the following auxiliary equipment and connections: fill, vent, return, sludge pump-out, low suction, high suction, steam smothering, fire-fighting connections, gage connection, suction box, suction or tank heater, steam connection, level indicator, temperature indicator, access manholes, ladders, piping, and valves. The amount of storage capacity installed depends on the mission of the base, availability of dependable supply, and frequency of delivery. Storage tanks and oil-burning equipment must be installed in accordance with the NFPA 30 "Flammable and Combustible Liquids Code," and NFPA 31, "Standard for the Installation of Oil Burning Equipment.

a. Fuel Oil Preparation. No. 2 and No. 4 oil normally only require a pump set to transfer oil from storage to the burner. Paraffin base No. 4 oil may also require a small amount of heating. The use of day tanks and transfer pumps may be necessary if main storage tanks are located remotely from the plant. No. 5 and No. 6 oil require pumping and heating equipment to prepare and move the oil to the combustion equipment. Figure 2-47 illustrates a duplex pumping and heating set. A pressure regulatory valve is provided to return unneeded oil to the storage or day tank before it is heated. This avoids overheating of storage tanks in addition to maintaining the desired oil pressure. Insulation of oil, steam, and condensate lines is required, and electric or steam heat tracing of lines may be required in some applications.

b. Safety Equipment. The NFPA establishes requirements for safe boiler operation for boilers with 10,000 pounds of steam per hour and larger. These requirements are contained in NFPA 85A, "Standard for Prevention of Furnace Explosions in Fuel Oil- and Natural Gas-Fired Single Burner Boilers-Furnaces". Figures 2-48 and 2-49 show schematic arrangements of safety equipment for oil-fired water tube and fire tube boilers, respectively. Standards for oil-fired multiple burner boilers are found in NFPA 85D. For boilers rated less than 10,000 pounds of steam per hour, Underwriters Laboratories Inc., Underwriters Laboratories of Canada, or other nationally recognized organizations establish safety requirements and tests, and approve safety equipment.

2-23. GAS-FIRING EQUIPMENT.

Natural gas is an easy and clean fuel to burn and requires less equipment and maintenance than coal or oil systems. Its disadvantages include higher cost than coal, uncertain and limited availablity, and a greater danger of explosion. Paragraphs 1-4c, 1-9, and 1-9a describe the potential for explosions and some of the necessary precautions. Early gas-firing equipment used gas velocity to aspirate air into the burner throat, where it was premixed with the gas

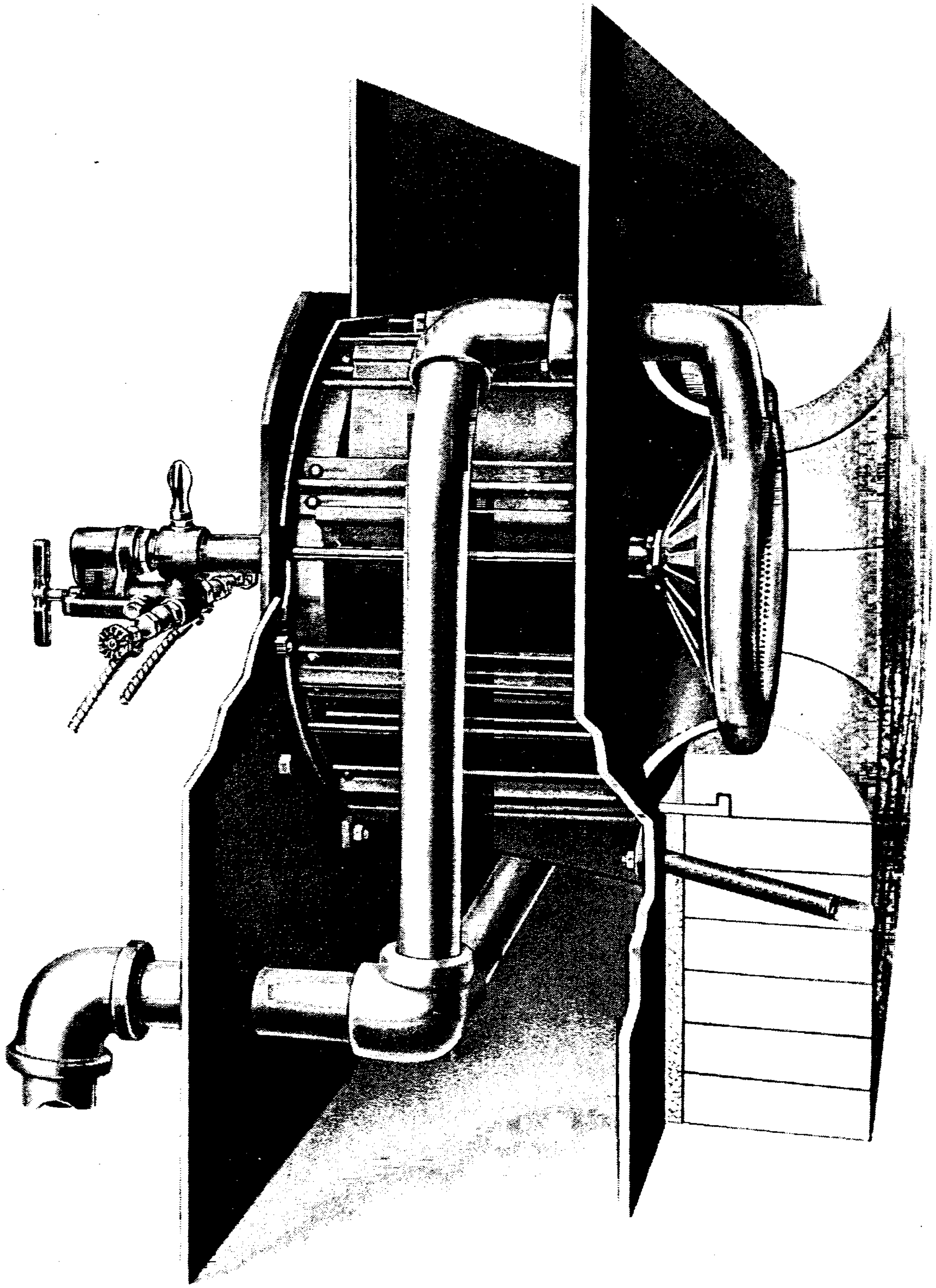


FIGURE 2-43. REGISTER BURNER

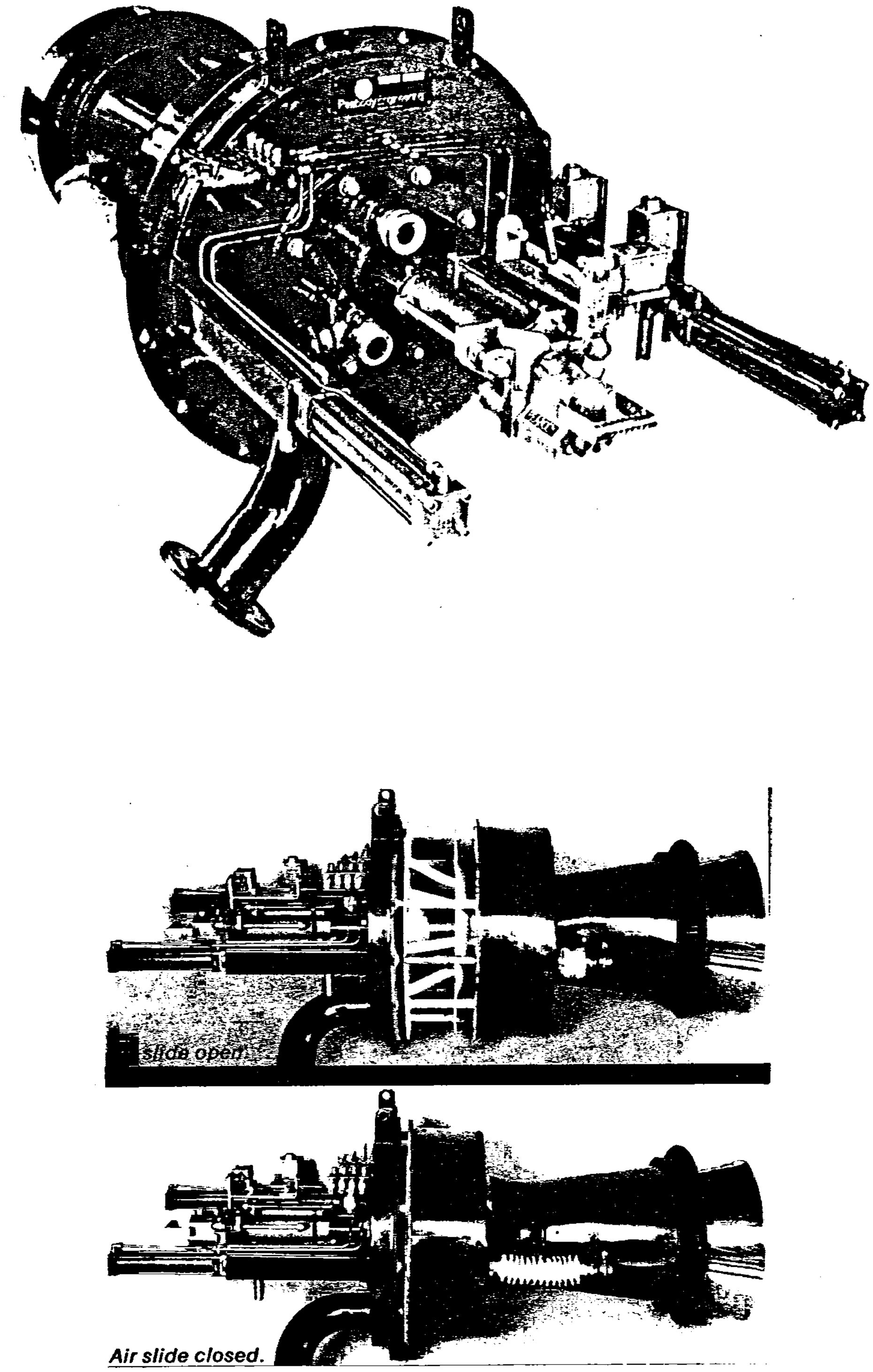
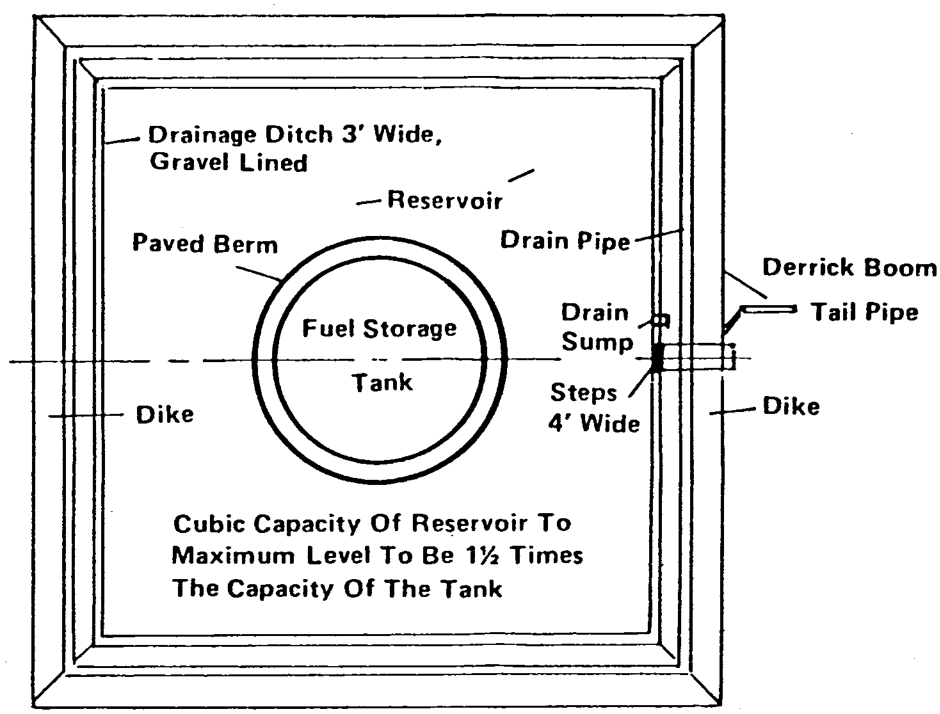
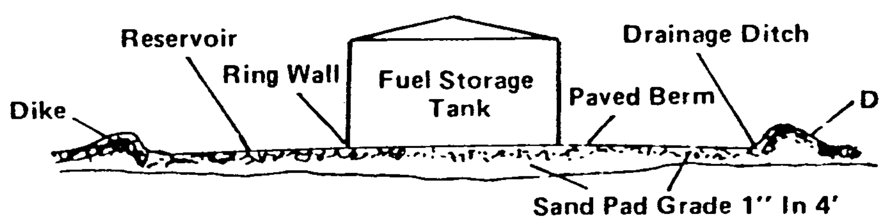


FIGURE 2-44. LOW EXCESS AIR BURNER



Plan View Of Tank Enclosure



Section Through Tank Enclosure

FIGURE 2-45. ARRANGEMENT OF ABOVE-GROUND FUEL OIL TANK

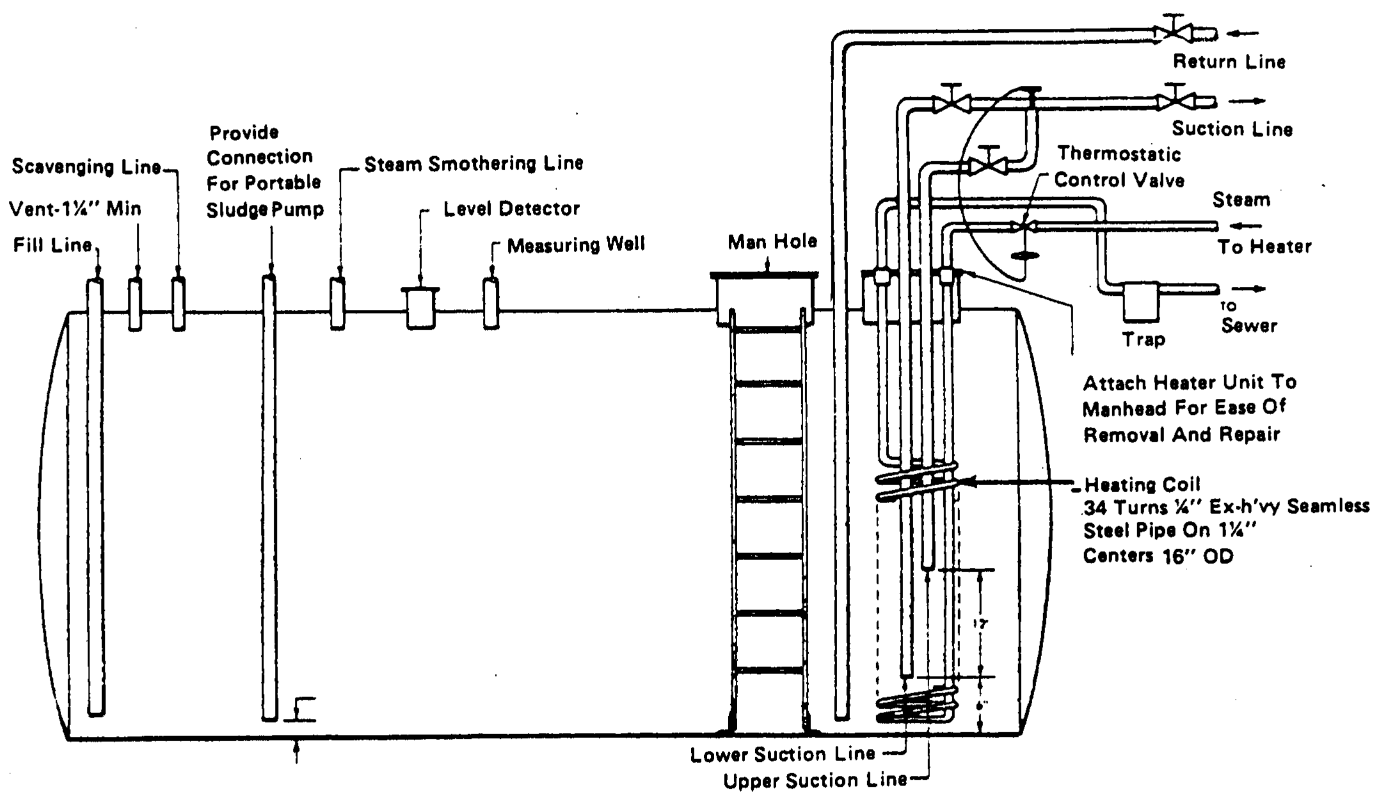


FIGURE 2-46. UNDERGROUND FUEL OIL STORAGE TANK

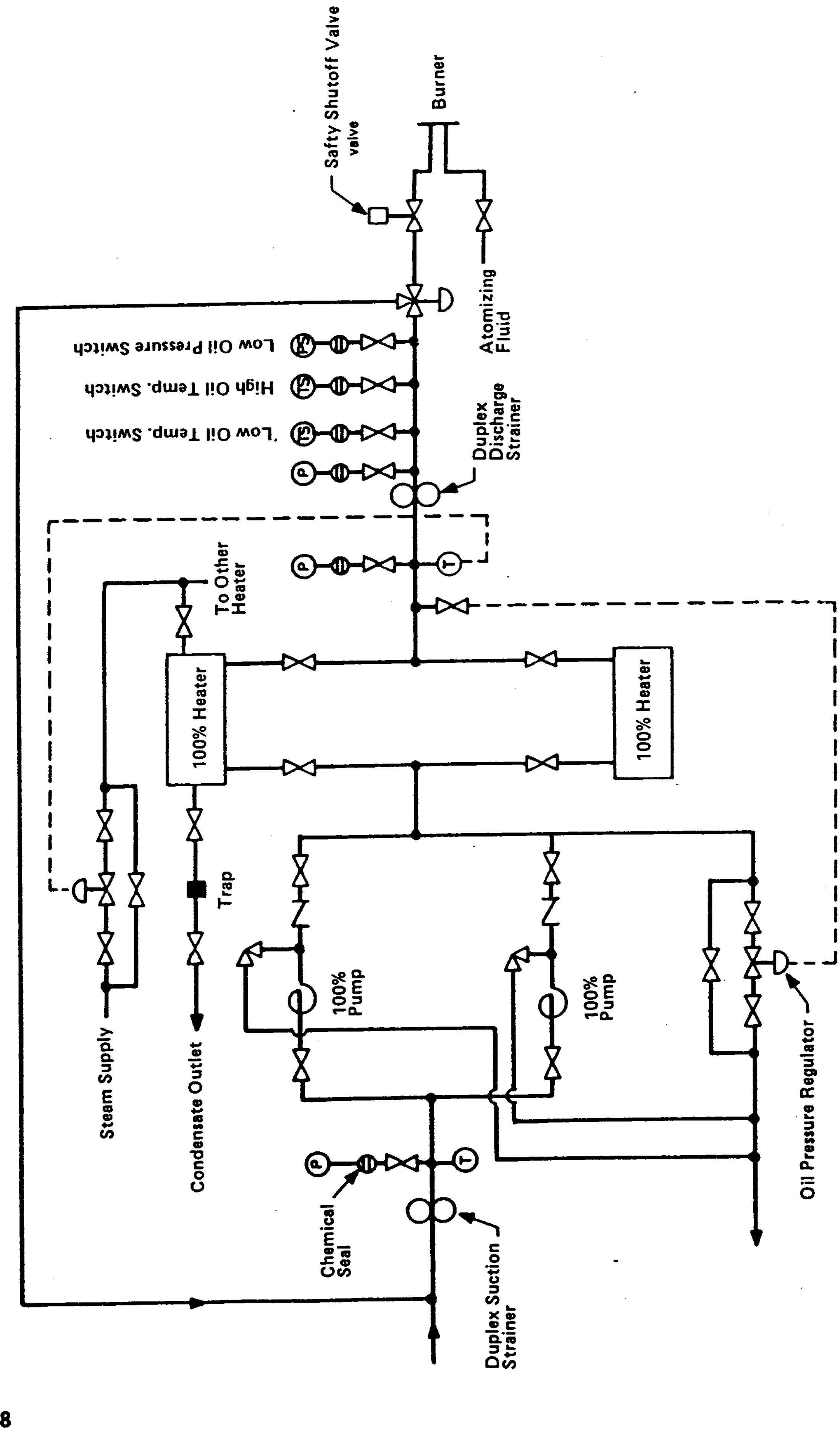
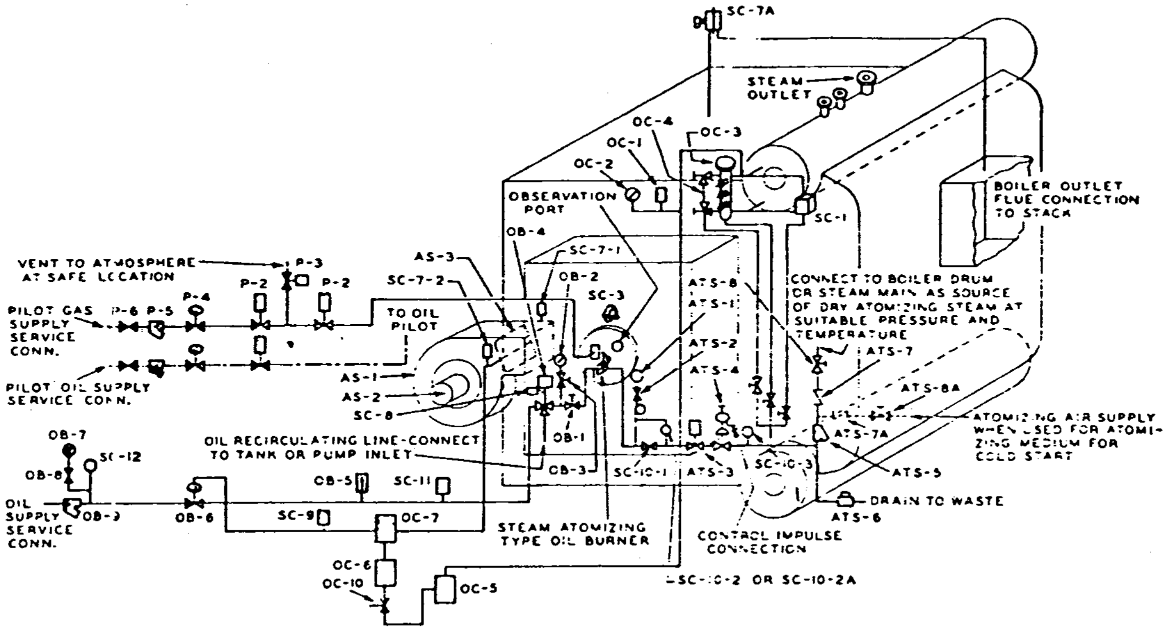


FIGURE 2-47. FUEL OIL PUMPING AND HEATING EQUIPMENT



OIL FIRING ONLY

Typical Schematic Arrangement of Safety Equipment
Fuel Oil-Fired Watertube Boiler with One (1) Burner
Automatic (recycling) or Automatic (non-recycling) Controls

LEGEND

Atomizing Steam System:

- ATS-1 Burner atomizing steam pressure gage
- ATS-2 Burner atomizing steam pressure gage cock
- ATS-3 Atomizing steam shut-off valve
- ATS-4 Atomizing steam differential pressure control valve
- ATS-5 Atomizing steam supply strainer
- ATS-6 Atomizing steam supply trap
- ATS-7 Atomizing steam supply check valve
- ATS-7A Atomizing air supply check valve
- ATS-8 Atomizing steam supply shut-off valve
- ATS-8A Atomizing air supply shut-off valve

Air System:

- AS-1 Forced draft fan
- AS-2 Forced draft fan motor
- AS-3 Forced draft fan control damper at inlet or outlet

Igniter (Pilot) System — Gas or Oil:

- P-2 Safety shutoff valves — auto. opening, spring closing (NC)
- P-3 Vent valve — auto. closing, spring opening (NO)
- P-4 Pressure regulating valve — optional depending on igniter pressure requirements.
- P-5 Strainer
- P-6 Manual plug cock

Oil Burner System:

- OB-1 Manual oil shutoff valve
- OB-2 Oil burner pressure gage
- OB-3 Oil burner pressure gage cock
- OB-4 Safety shutoff and recirculating valve
- OB-5 Oil temperature thermometer or gage (Note 4)
- OB-6 Oil control valve
- OB-7 Oil supply pressure gage
- OB-8 Oil supply pressure gage cock
- OB-9 Oil strainer

Safety Controls: (All switches in "hot" ungrounded lines. See 4662)

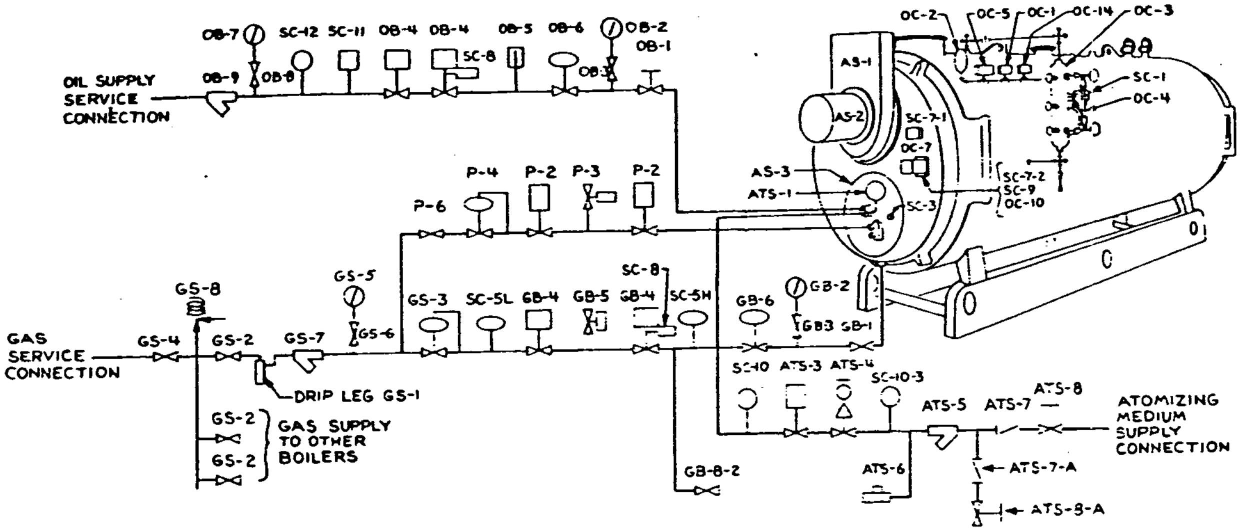
- SC-1 Low water cut out integral with column or separate from water column
- SC-3 Flame scanner
- SC-7-1 Windbox pressure switch (Note 2)
- SC-7-2 Fan damper position switch (Note 2)
- SC-7A Purge airflow switch (Note 2)
- SC-8 Closed position interlock on OB-4
- SC-9 Light-off position interlock
- SC-10-1 Atomizing steam flow interlock orifice
- SC-10-2 Atomizing steam flow interlock differential pressure switch
- SC-10-2A Atomizing steam pressure interlock switch
- SC-10-3 Atomizing steam supply pressure interlock switch
- SC-11 Low oil temperature interlock (Note 4)
- SC-12 Low oil supply pressure interlock

Operating Controls & Instruments:

- OC-1 High steam pressure switch (Note 1)
- OC-2 Steam drum pressure gage
- OC-3 Water column with high & low level alarms
- OC-4 Water gage and valves
- OC-5 Steam pressure controller
- OC-6 Manual auto. selector station
- OC-7 Combustion control drive unit or units
- OC-10 Modulating control low fire start positioner

NOTES:
1. With automatic (non-recycling) control, an overpressure shutdown requires manual restart.
2. Purge airflow may be proved by providing either SC-7-1 and SC-7-2 (and similar devices for other dampers which are in series) or SC-7A.
3. Atomizing steam interlock may be accomplished by providing either SC-10-1 and SC-10-2 or SC-10-2A and SC-10-3.
4. Temperature interlock and thermometer omitted for light oils which do not require heating.
5. Arrangement shown is applicable to straight mechanical pressure atomizing oil burners by omitting atomizing steam system.

FIGURE 2-48. SAFETY EQUIPMENT OIL-FIRED WATER TUBE BOILER



ALTERNATE GAS OR OIL FIRING

Typical Schematic Arrangement of Safety Equipment
Gas- and Oil-Fired (alternately) Firetube Boiler With One (1) Burner
Automatic Recycling Controls

LEGEND

Atomizing Medium System (See Note 5):
- ATS-1 Atomizing pressure gage
- ATS-3 Atomizing medium shut-off valve
- ATS-4 Atomizing medium differential pressure control (if req'd.)
- ATS-5 Atomizing medium supply strainer
- ATS-6 Atomizing steam supply trap
- ATS-7 Atomizing steam supply check valve
- ATS-7A Atomizing air supply check valve
- ATS-8 Atomizing steam supply shut-off valve
- ATS-8A Atomizing air supply shut-off valve

Gas Supply System:
- GS-1 Drip leg
- GS-2 Manual plug cock
- GS-3 Gas supply pressure reducing valve
- GS-4 Manual gas supply shut-off valve
- GS-5 Gas supply pressure gage
- GS-6 Gas supply pressure gage cock
- GS-7 Gas cleaner
- GS-8 Relief valve

Air System:
- AS-1 Forced draft fan
- AS-2 Forced draft fan motor
- AS-3 Forced draft fan control damper at inlet or outlet

Igniter (Pilot) System:
- P-2 Safety shut-off valve, auto. opening, spring closing (NC) (See Note 6)
- P-3 Vent valve, auto. closing, spring opening (NO)(See Note 6)
- P-4 Gas pressure regulating valve optional, depending on ignitor pressure requirements
- P-6 Manual plug cock

Gas Burner System:
- GB-1 Manual plug cock
- GB-2 Gas burner pressure gage
- GB-3 Gas burner pressure gage cock
- GB-4 Safety shut-off valves, auto, draining, spring closing (NC)
- GB-5 Vent valve, auto. closing, spring opening (NO)
- GB-6 Gas fuel control valve
- GB-8-2 Leakage test connection downstream safety S.O. valves

Oil Burner System:
- OB-1 Manual oil shut-off valve
- OB-2 Oil burner pressure gage
- OB-3 Oil burner pressure gage cock
- OB-4 Safety shut (with recirculation-optional)
- OB-5 Oil temperature gage (See Note 4)
- OB-6 Oil control valve
- OB-7 Oil supply pressure gage
- OB-8 Oil supply pressure gage cock
- OB-9 Oil strainer

Safety Controls (All Switches in Hot Ungrounded Lines):
- SC-1 Low water cut-out (integral with or separate from water column)
- SC-3 Flame scanner
- SC-5H Gas supply high pressure switch
- SC-5L Gas supply low pressure switch
- SC-7-1 Windbox pressure switch (See Note 2)
- SC-7-2 Fan damper position switch (See Note 2)
- SC-8 Closed position interlock on GB-4 (overtravel)
- SC-9 Light-off position interlock
- SC-10 Atomizing medium pressure interlock switch
- SC-10-3 Atomizing medium supply pressure interlock switch
- SC-11 Low oil temp. interlock (See Note 4)
- SC-12 Low oil supply pressure interlock

Operation Controls & Instruments:
- OC-1 High steam pressure switch (See Note 3)
- OC-2 Steam drum pressure gage
- OC-3 Water column (may be equipped with low water cut-out and feedwater pump control)
- OC-4 Water gage and valves
- OC-5 Steam pressure controller
- OC-7 Combustion control drive unit
- OC-10 Modulating control — low fire start positioner
- OC-14 Excessive steam pressure switch (See Notes 1 & 3)

NOTES:
1. Actuation of this switch normally requires manual reset.
2. Purge air flow may be proven by providing SC-7-1 and/or SC-7-2.
3. For hot water boilers, switches OC-1, OC-5 and OC-14 would be temperature sensing device.
4. Temperature interlock and thermometer omitted for light oils which do not require heating.
5. Arrangement shown is applicable to straight mechanical pressure atomizing or burners by omitting atomizing medium system.
6. For pilots of less than 400,000 BTU/HR the vent valve (P-3) may be eliminated and only one safety shut-off valve (P-2) may be required.

FIGURE 2-49. SAFETY EQUIPMENT OIL- OR GAS-FIRED FIRE TUBE BOILER before burning. Premix burners are now used for igniter service. The advent of forced draft fans and the need for increased burner capacity brought about the development of nozzle-mix gas burners. Nozzle-mix burners are capable of handling gas over a wide range of pressures depending on the design. Types of nozzle-mix burners include ring, gun, and multiple spud.

Figure 2-43 illustrates a register burner equipped with gas spuds nd an oil atomizer. Figure 2-44 illustrates a low excess air burner equipped with a gas ring. NFPA 85A, "Standard for Prevention of Furnace Explosions in Fuel Oil- and Natural Gas-Fired Single Burner Boilers-Furnaces," establishes requirements for safe operation of gas-fired boilers. Figures 2-49 and 2-50 show schematic arrangements of safety equipment for gas-fired fire tube and water tube boilers. "Standards for Natural Gas-Fired Multiple Burner Boilers" are found in NFPA 85B. For boilers rated less than 10,000 pounds of steam per hour, standards are set by Underwriters Laboratories Inc., Underwriters Laboratories of Canada, and other nationally recognized organizations.

2-24. LIQUEFIED PETROLEUM GAS.

Liquefied petroleum gas (LPG) is used for igniter service and occasionally as a standby fuel for natural gas- or oil-fired installations. LPG is a combination of propane and butane maintained in a liquid state through storage under pressure. NFPA Standards 58 and 54, Part 2 establish requirements for the storage and handling of LPG. For further information on LPG, refer to the Air Force Manual, No. 85-12.

SECTION IV. CONTROLS AND INSTRUMENTATION

Controls and instrumentation are an integral and essential part of all central boiler plants. They serve to assure safe, economic and reliable operation of the equipment. They range from the simplest of manual devices to completely automated, microprocessor-based systems for control of boilers, turbines, and even end-users of energy. The subjects of controls and instrumentation are so intimately related that they are difficult to separate, and are discussed in parallel in the following chapter. Only those systems and items which are commonly used in central boiler plants are discussed.

2-25. FEEDWATER-DRUM LEVEL CONTROLS.

The importance of an adequate, properly controlled supply of feedwater to a boiler cannot be overemphasized. Boiler feedwater pumps and injectors (paragraph 2-38), low water fuel cutoffs (paragraph 2-27), and feedwater heaters (paragraph 2-37) are all part of an effective feedwater system. Steam boilers also require drum level controls to maintain the water level within limits established by the manufacturer. Operating with water levels that are too high may cause carryover of water from the drum, while opeating with levels that are too low can result in boiler tube failures due to insufficient cooling. Feedwater regulators are used to adjust the feedwater flow rate and maintain proper levels. Five types of feedwater regulators are commonly used: positive displacement, thermohydraulic, thermostatic, pneumatic level transmitter/cintroller, and lectronic level transmitter/controller. Each is described below.

a. Positive Displacement. The positive-displacement type feedwater regulator (figure 2-51) is connected to the boiler drum or water column so that the average water level in the chamber is in line with that of the drum. The rise and fall of the float with the water level actuates a balanced feed valve through a suitable system of levers, and reduces or increases the flow of water to the boiler. The entire mechanism is in the pressure space and there are no stuffing boxes to leak or bind. The float is initially charged with a small amount of alcohol, which vaporizes and pressurizes in the float to counterct the boiler pressure exerted on the outside of the float. The valve and linkage are designed to give a gradual and continuous change in water flow between the high and low limits. This type of control will maintain a different water level for each steam flow produced by the boiler.

b. Thermohydraulic. Operation of the thermohydraulic or vapor-generator type of feedwater regulator (figure 2-52) depends upon the principle that steam occupies a greater volume than the water from which it was formed. The equipment consists of a generator, a diaphragm-operated valve, and the necessary connecting pipe and tubing. The central tube of the generator is connected to the boiler drum or water column, with the tube inclined so that the normal drum water level is slightly above the center of the generator. The generator, tubing and diaphragm chamber are filled with hot water. In operation, heat from steam in the upper portion of the inner tube raises the temperature of the water surrounding that portion of the tube and converts part of it to steam. This increases the pressure in the generator, forcing part of the water out of the generator until the water level is the same in both the inner and outer tubes. The water which is